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AUTOMATED PROSTATE VOLUME DETERMINATION WITH ULTRASONOGRAPHIC IMAGING

RENÉ G. AARNINK, ANTON L. HUYNEN, ROBERT J. B. GIESEN, JEAN J. M. C. H. DE LA ROSETTE, FRANS M. J. DEBRUYNE AND HESSEL WIJKSTRA

From the Department of Urology, University Hospital Nijmegen, Nijmegen, The Netherlands

ABSTRACT

A method for automated determination of the prostate volume based on planimetric volumetry was developed to overcome subjectivity in prostate volume measurements using ultrasonography. An edge detection method is applied to locate the prostate boundary in sequential ultrasonographic images. During regular examinations, the volume was assessed automatically in 55 patients. The Pearson correlation coefficient of the automated volume compared to the reference prostate volume was 0.93. The estimated ratio of the automated volume to the reference volume was 0.92. This method overcomes the individual subjectivity when interpreting ultrasonographic images, and provides accurate and objective results for followup of benign prostatic hyperplasia treatments and for comparison of multicenter trials. Also, this method is a useful tool for objective determination of prostate specific antigen in proportion to the volume (prostate specific antigen density).

KEY WORDS: ultrasonography; prostate; image analysis, computer-assisted; prostatic hypertrophy

Prostate volume may be an important parameter in the investigation of patients with complaints of prostatism. It is used to decide between possible treatment modalities (transurethral prostatectomy versus suprapubic prostatectomy) and also as a criterion in the evaluation and followup of (non)operative treatment of patients suffering from benign prostate hyperplasia (BPH) or prostate cancer.[1] Essential to any clinical study of drug therapy for prostate volume reduction is an accurate and reproducible method to determine the decrease in size of the prostate gland at intervals. Moreover, volume-corrected prostate specific antigen (PSA) values can be useful to distinguish between patients with BPH and prostate cancer.[2–4] Overlap in PSA levels occurs in patients with a normal prostate, BPH and cancer. Correction of PSA values for the prostate volume may improve the discriminating power.[2]

A rough estimate of the prostate volume will provide sufficient information to select the appropriate treatment. To assess the efficacy of drug therapy, however, small changes in prostate size could be of value, and should be detectable and measurable. Also, for PSA density determination, accurate volume measurements are necessary. Although the PSA serum level determination is accurate, the PSA density value is disturbed by an inaccurate volume estimation. In the literature as well as in our own experience, variations up to 30% are found in volume determinations caused by time pressure errors, interpretation differences or differences in measuring methods,[5–12] leading to a maximum variation in PSA density of 42.9%.

Estimation of the prostatic volume by digital examination is an inaccurate procedure.[5] Other techniques have been proposed for volume determination, including estimation at cystoscopy and urethral pressure profilometry.[7] Introduction of ultrasound for prostatic imaging resulted in new possibilities.[2,3,6–8,13] High frequency transrectal ultrasound for prostate examination is largely preferred because of the higher failure rate of transabdominal ultrasound.[10]

Several methods using ultrasonography have been proposed for volume determination including planimetric volumetry that calculates the volume from the sum of sequential areas in cross-sectional images of the prostate,[13] morphological approximation by applying the formula for elliptical volume[6,10] or variations of this formula,[9] and volume estimation using the maximum transverse area outlined manually by the investigator together with the length of the prostate.[6] In the literature, studies are reported concerning reproducibility of prostate volume measurements using ultrasound. Fehr and Knönagel examined 23 men in stage 1 (no medication) of a drug therapy study of BPH at intervals of 2 to 4 weeks and found a maximum variation of 13% for the volume in 142 evaluated suprapubic measurements.[12] They concluded that during drug therapy only a decrease of 15% or more in prostate volume is significant for suprapubic measurements. Styles et al showed a Spearman rank correlation coefficient of 0.91 among transrectal ultrasound measurements in 28 patients by 2 urologists using the elliptical formula.[10] The mean difference in prostate volume obtained by 2 urologists was slight (4 ± 11 cc) but the standard deviation was great, reflecting a wide variation in the individual patient.

Stone et al conducted a multicenter double-blinded randomized drug therapy study with 3 methods for transrectal ultrasound volume determination, obtaining the prostate volume twice from every patient taking a placebo at 3-month intervals.[11] Because planimetric volumetry using transrectal ultrasound provided the lowest variability (5% volume variation in 15 patients), they concluded that planimetric volumetry should be the method of choice in (multicenter) followup of BPH treatments. Jones et al demonstrated that planimetric volumetry provides good results compared to the actual volume when the prostate boundary is intact.[8] When the boundary is poorly defined or not ultrasonically visible because of cancer unconfined by the boundary the measurements were often inaccurate or impossible.

Terris and Stamey performed a study of prostate volume determination in 150 men undergoing radical prostatectomy using 15 different volume estimates.[9] They concluded that step-section planimetry is accurate but extremely time-consuming, tedious for the sonographer and prolongs the discomfort of the examination for the patient. They revealed that formula derived volumes can be used clinically. The dimensions needed in the formulas (transverse and antero-

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posterior dimensions) are obtained in the prostate section with approximately the largest transverse dimension.

Because of its accurate results,[9,11] we decided to develop an automated method based on planimetric volumetry. Instead of manual outlining, the prostate contour is located automatically in every cross section. The method has been developed to overcome the subjectivity of interpreting transrectal ultrasound images for volume measurements, thus, obtaining more objective and reproducible results. It has been implemented in an automated urological diagnostic expert computer system, which has been developed for the early diagnosis of prostate cancer using tissue characterization in ultrasonographic prostate images.[14] In our study the accuracy of the automated method for prostate volume determination was tested in a clinical environment. The prostate volume was determined automatically using images stored with the system during everyday examinations. The automated results were compared to clinical volume measurements as performed routinely.

MATERIALS AND METHODS

During regular ultrasonographic examinations, a Kretz combison 330 ultrasound scanner with standardized settings[14] was used with a 7.5 MHz. transrectal multiplane 3-dimensional transducer. This scanner has a built-in volume metering method based on planimetric volumetry. 3-Dimensional ultrasonographic information of a conicle volume of approximately 150 cc is read into the memory of the machine. By placing this volume over the prostate, 3-dimensional information of the prostate is stored in the computer. This information is used for manual outlining of the contour in sequential prostatic cross sections in the transverse, longitudinal or sagittal planes using a track ball.

The computer system is connected to the video output signal of the echo scanner. This system consists of an ordinary personal computer (80486DX2, 50 MHz.) with an additional image processing card. For automated determination of the prostate volume a series of consecutive cross sections in the transverse plane was stored on hard disk. The prostate was imaged in the transverse plane starting at the base, and cross-sectional images were stored every 4 mm. by retracting the probe with a fixture until the apex of the prostate was reached. During regular prostatic examinations, a series of ultrasonographic cross sections of 56 unselected patients (44 to 94 years old, average age 68.1 years) with prostatic complaints was collected. Reasons for ultrasonographic examinations were positive digital rectal examination in 13 patients, elevated (greater than 4.0 ng./ml.) PSA level in 18, suspected transrectal ultrasonography at initial examination in 3 or a combination of events in 22. In 45 patients the examination was followed by guided biopsies resulting in malignancy in 10, suspected histology in 2, prostatitis in 18 and benign histology in 15.

To outline the prostate in the images automatically, edge detection techniques were used. These techniques are based on detecting certain features, that is dark-light transitions, in images. These transitions in gray level were detected using derivatives. A zero-crossing in the second derivative located the position of the gray level transitions (edges) and the value of the gradient at that location provided the strength of that edge. By selecting the correct edges and interpolating them to form a closed contour, the boundary of the prostate was located. The boundary detection technique has been described extensively previously.[15]

To test the accuracy of the automated method for prostate volume determination, 3 other methods were applied: 1) the volume measurement method with manual outlining in the longitudinal plane as available on the Kretz ultrasound scanner, which is routinely used to obtain the clinical volume, 2) the volume measurement method on the scanner in the transverse plane during the same investigation to evaluate intra-urologist interpretative differences in manual outlining and 3) planimetric volumetry by manual outlining of the prostate contour in the series of cross sections stored for the automated determination in an off-line drawing session in quiet surroundings by an experienced urologist. Off-line manual outlining leads to good results when the investigator is making an effort to outline exactly[16] and, therefore, can serve as a reference volume.

During the ultrasonographic examinations, the measurements on the echo scanner were performed first. All measurements were performed by 1 urologist (J. d. l. R.) experienced in transrectal ultrasound. Then, the images needed for automated volume determination were stored together with the results of the manual outlining. After storing the series of transverse images (within 1 minute), the volume determination was started off-line and the automated detected contours were presented to the user. A possibility for manual correction of these contours is implemented in the program but has not been used in this study.

RESULTS

Examples of prostate contours detected by the computer are presented in figures 1 and 2, including an image of benign prostate tissue with calcifications (figs. 1, *A* and 2, *A*), an image of malignant tissue confirmed by radical prostatectomy specimens without ultrasonographic suspicion (figs. 1, *B* and 2, *B*) and an image of malignant tissue confirmed by radical prostatectomy specimens with a hypoechoic lesion clearly visible, indicated by white arrows (figs. 1, *C* and 2, *C*). These images are selected to present 3 possible ultrasonographic appearances in prostatic imaging. Extracting the

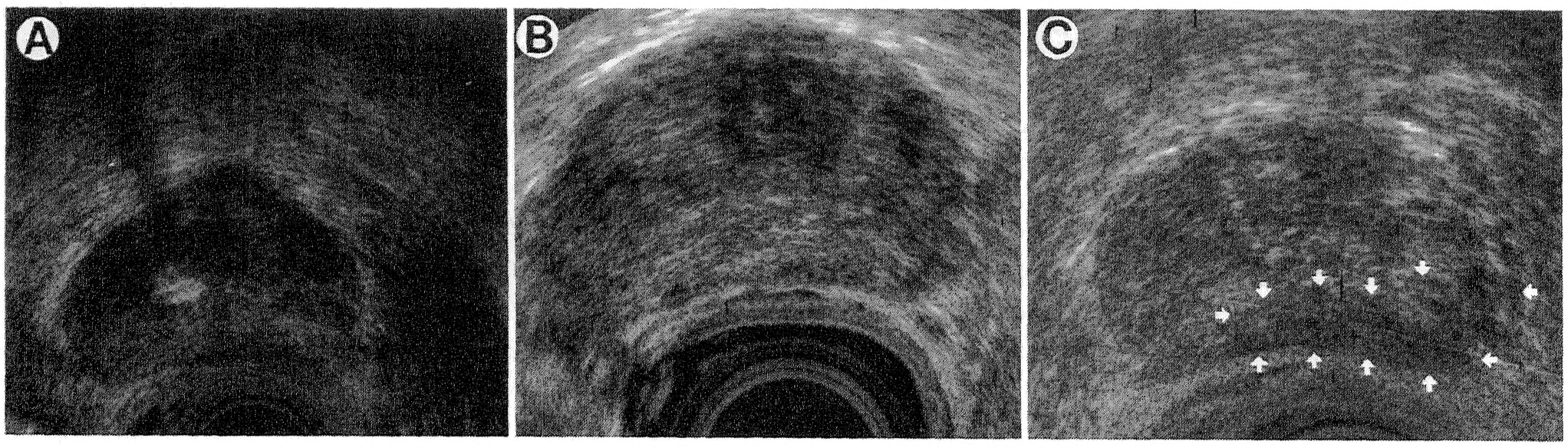

FIG. 1. Examples of transverse prostate cross sections by transrectal ultrasound. *A*, benign prostate tissue with calcifications disturbing ultrasonographic information of prostate boundary. *B*, malignant prostate tissue confirmed by radical prostatectomy without visible lesions. *C*, malignant tissue with clearly visible hypoechoic lesion on left side of prostate (arrows).

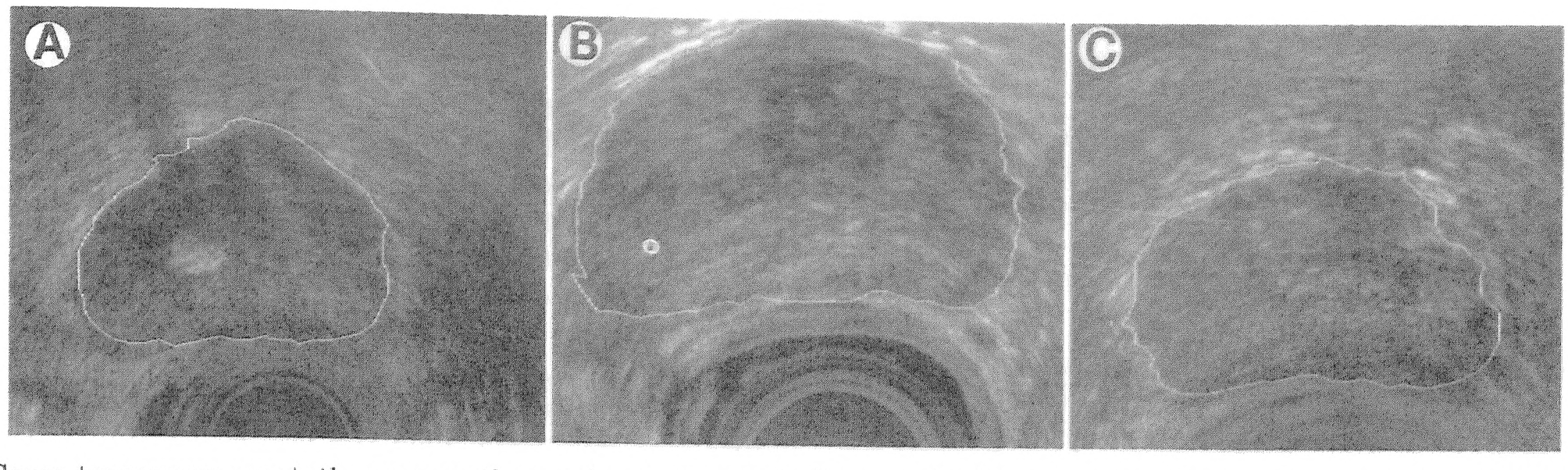

FIG. 2. Same transverse prostatic cross sections using transrectal ultrasound with automated detected prostate boundaries. *A*, benign prostatic tissue with calcifications. *B*, malignant prostate tissue without visible lesions. *C*, malignant tissue with visible lesion.

contour in 1 transrectal ultrasound image takes approximately 20 seconds, while for an entire series of cross sections approximately 4 minutes are needed. Because the determinations of contours and volume are performed off-line, no additional time is needed during the ultrasonographic examination.

In 1 patient ultrasonographic examination resulted in a poor image quality (disturbances by calcifications and lack of contrast enhancement). The automated method provided a result of 30 cc, while the reference volume was 157 cc. The poor image quality is also reflected by the manual measurements (81 cc as clinical volume and 61 cc as transverse volume). This patient was excluded from further analysis of the results.

The numerical results of all 4 methods for 55 patients are shown in table 1, including mean volume, range and absolute average error with standard deviation when compared to the reference volume (in cc). Pearson's product moment correlation coefficient[17] (only reflecting the linear correlation between the measurements), and the estimated ratio coefficient[18] between the reference volume and the results of the other methods are presented together with the standard deviation for estimated ratio coefficient. The results show that the automated determination has the smallest absolute average error and the smallest standard deviation. The effects of human interpretation differences are illustrated by the large differences between the results obtained in the transverse and longitudinal planes. Outlining of the prostate in the transverse plane resulted in a volume approximately 19% smaller on the average for 55 patients compared to the results obtained in the longitudinal plane.

Figures 3 to 5 show graphic representations of the volume results of the 3 methods as a function of the reference volume. The ratio coefficients (estimated ratio coefficient plus or minus standard deviation) through the scatter points are plotted in the same graphs, with the best ratio coefficient of the automated method: 0.92 ± 0.15. Comparison of figures 3 and 4 shows the intra-urologist interpretation differences during clinical outlining of ultrasonographic images. Because of the large difference between the manual measurements with the ultrasound scanner in both planes, the accuracy of these measurements was evaluated using a volume phantom with a known volume of 33.2 cc (determined in a water bath). The results in the longitudinal (33.3 cc) and transverse (32.9 cc) planes were comparable to the results of the measurement in a water bath, which shows again that accurate volume measurement is possible in both planes when exact manual outlining is performed.

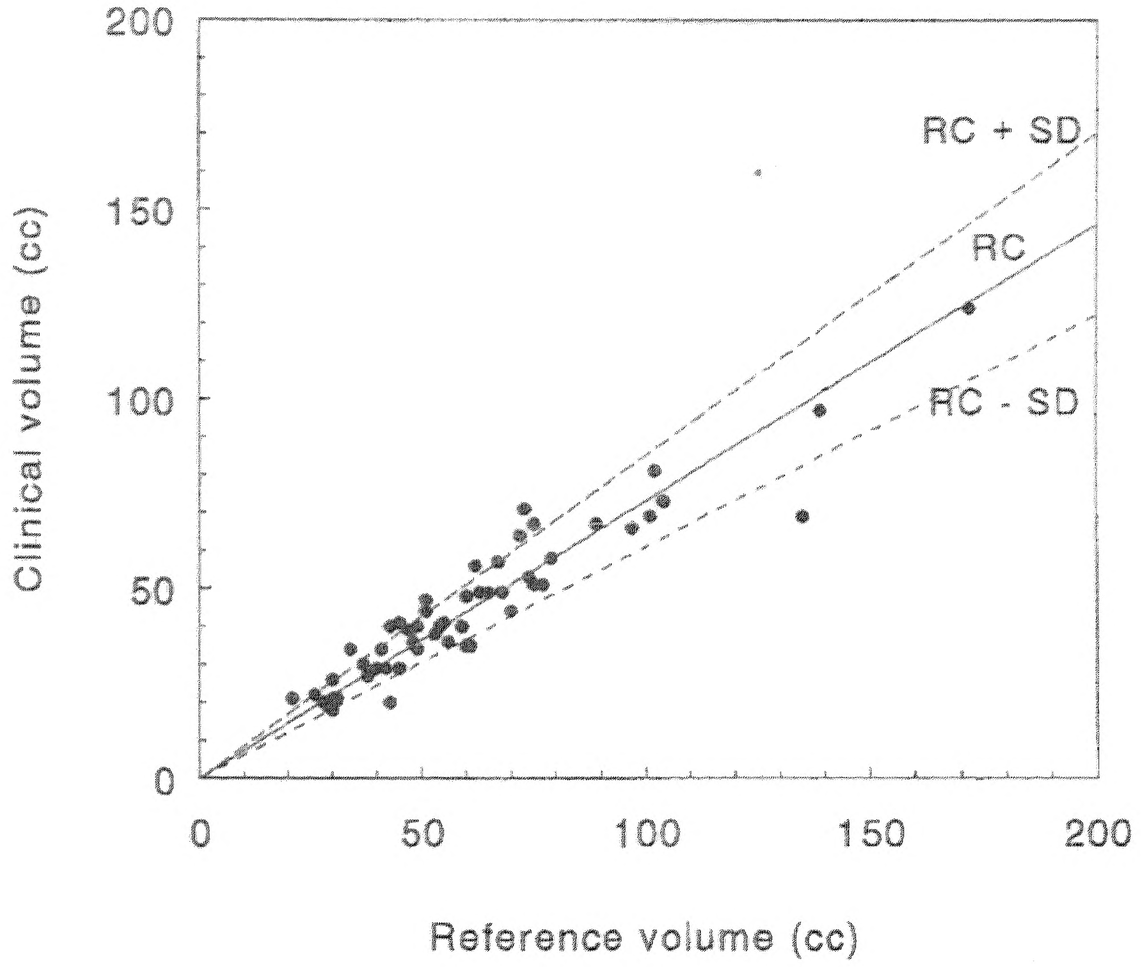

FIG. 3. Clinical volume (manual outlining in longitudinal plane) as function of reference volume for 55 patients. Also, ratio coefficient (*RC*), that is relationship between reference volume and clinical volume, is plotted together with range of standard deviation (*SD*).

Although the best results were obtained with the automated method, the standard deviation in the average error is rather large. Especially for a large prostate, larger errors occur (fig. 5). In tables 2 and 3 the results of the different methods are presented for different prostate sizes. Table 2 shows the results for prostates with a reference volume smaller than 50 cc, which is the maximum volume of the sphere that fits entirely within the conicle volume used for volume measurements with the scanner, while in table 3 the results are presented for the 32 patients with a reference volume of greater than 50 cc. Clinical volumes of greater than 50 cc are measured with a large underestimation, which is also reflected by the improved results for small prostates. In table 4 the results of a subpopulation with a reference

TABLE 1. *Results of 3 different volume determination methods for total population of 55 patients: track ball outlining in longitudinal plane (clinical volume), transverse plane (transverse volume) and automated outlining (automated volume)*

	Reference Vol.	Clinical Vol.	Transverse Vol.	Automated Vol.
Mean cc. vol. (range)	60.5 (21–172)	44.7 (18–124)	36.4 (15–127)	57.9 (26–124)
Av. error ± SD (cc)	—	15.8 ± 12.1	24.2 ± 14.7	7.2 ± 9.2
Ratio coefficient ± SD	—	0.73 ± 0.12	0.60 ± 0.11	0.92 ± 0.15
Pearson's correlation coefficient	—	0.94	0.92	0.93

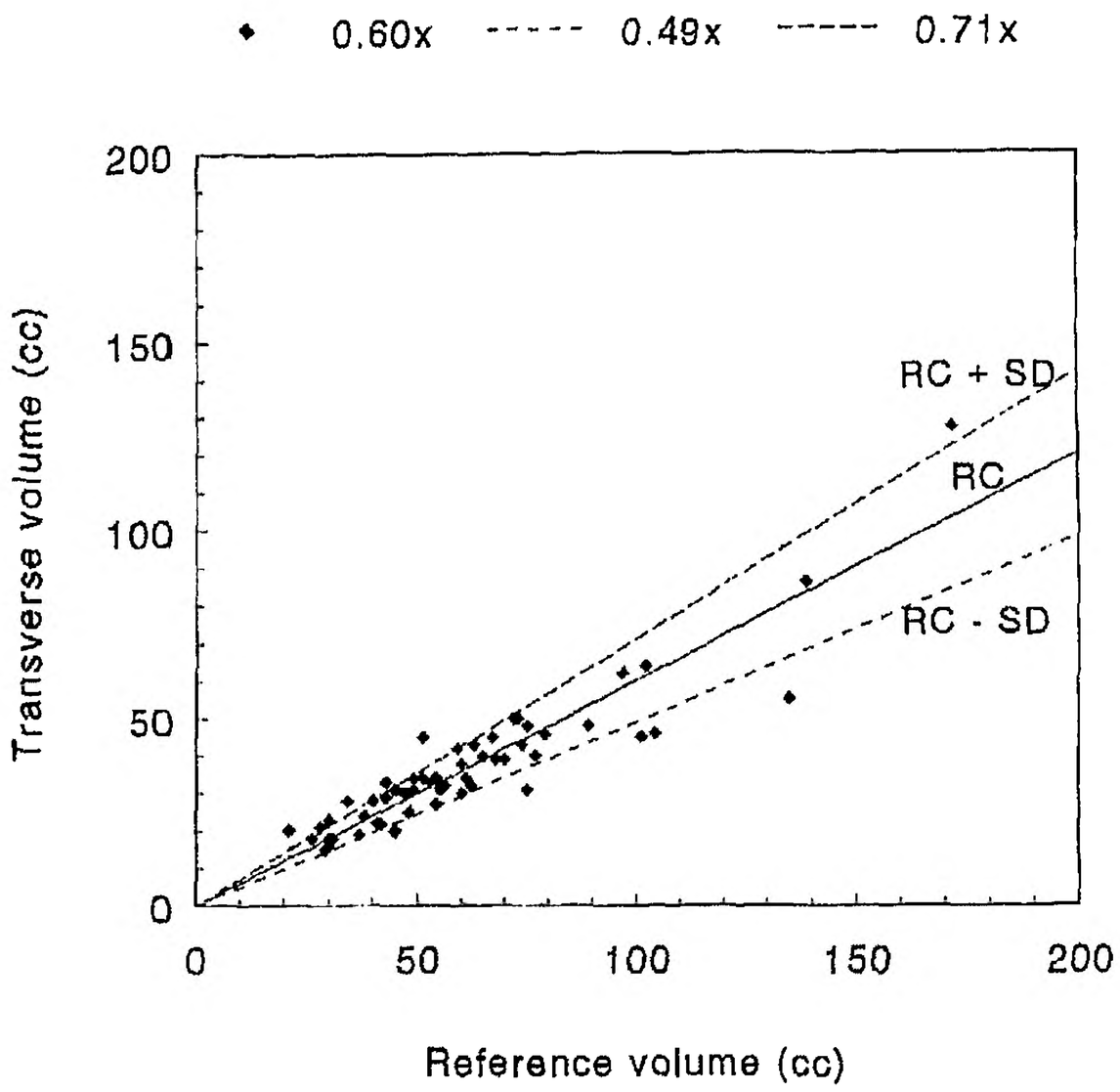

FIG. 4. Transverse volume, obtained by manual outlining in transverse plane, as function of reference volume for 55 patients. Also, ratio coefficient (*RC*), that is relationship between reference volume and transverse volume, is plotted together with range of standard deviation (*SD*).

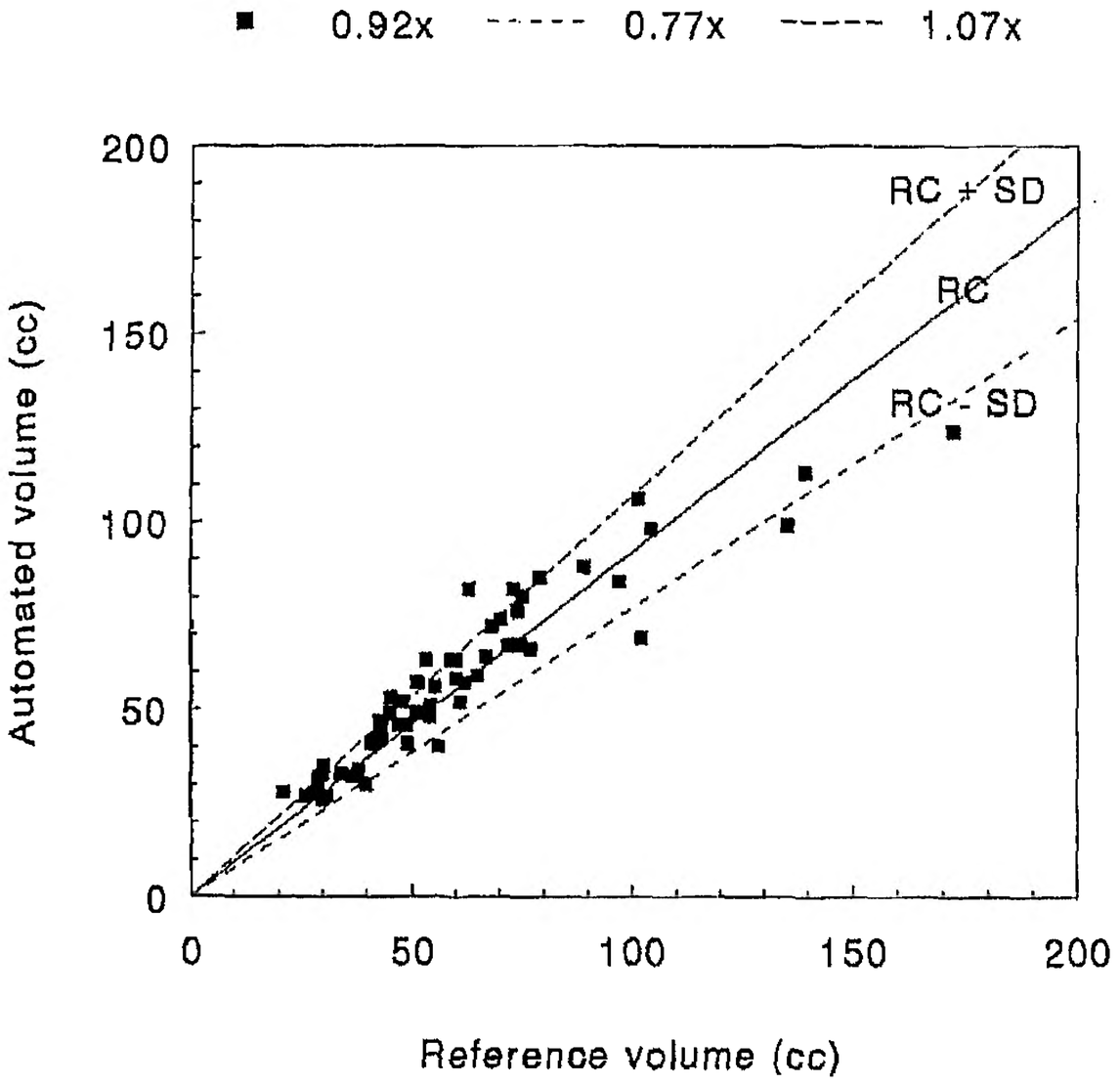

FIG. 5. Automated prostate volume determination (automated outlining in transverse plane) as function of reference volume for 55 patients. Also, ratio coefficient (*RC*), that is relationship between reference volume and automated volume, is plotted together with range of standard deviation (*SD*).

volume smaller than 100 cc is presented, including the large group of patients with a volume of 50 to 100 cc. For all methods the average error and its standard deviation decrease. Also, the ratios of the different methods to the reference volume improve and for the automated method the ratio even reaches 1.0. The automated results for the subpopulation of 23 patients with a reference prostate volume smaller than 50 cc are comparable to the results in the 49 patients with a reference volume smaller than 100 cc.

DISCUSSION

The volume results presented show that the automated method leads to good results when compared with the reference volume. The selection of the reference volume is based on the results of planimetric volumetry obtained at our clinic by Hendrikx et al.[16] In a cadaver study, they showed good correlation between the volume obtained with transrectal ultrasound and the prostate volume measured after prostatectomy (the gold standard). The measurements with transrectal ultrasound were performed by an experienced urologist during sessions without time pressure (the same urologist who performed the clinical examinations). Therefore, we concluded that the results of manual outlining by a urologist experienced in ultrasonography during an off-line drawing session in quiet surroundings can serve as a reference volume. During this session, the results obtained clinically were unknown to the urologist (J. d. l. R.).

The method for automated prostate volume determination is based on planimetric volumetry. The disadvantages of planimetric volumetry mentioned by Terris and Stamey[9] can be overcome using an additional computer to the echo scanner. By storing the cross sections on the computer before outlining the prostate contour, the time needed during the ultrasonographic examination is decreased. The time needed for outlining of the prostate contours on the echo scanner is estimated to be approximately 5 minutes. It takes approximately 6 minutes to obtain the result of the reference volume. No other time than that to store the images on hard disk (approximately 1 minute) is needed for the automated volume determination. Therefore, the discomfort of the examination for the patient is lessened as well as the influences of movement artifacts of the patient. Because the outlining is performed by the computer, the method is less tedious for the sonographer.

The results of the automated method are not dependent on the interpretation of the investigator but on the image quality and boundary presentation. For 1 patient the automated method was not able to determine the prostate contours correctly because of poor image quality. In this case manual correction had to be performed to obtain the correct prostate volume. The results presented are obtained using 1 echo scanner by 1 urologist (J. d. l. R.) experienced in ultrasonography. In a multicenter trial with urologists less experienced in ultrasound, the clinical results may vary more. The influence of using different scanners with different image representations on the accuracy of the automated method must be investigated.

The clinical measurements of large prostates are less accurate than those of smaller prostates. These errors may be introduced by interpretation errors of the urologist because the prostate boundary is outside the focus region of the echo scanner.[11] Besides, they may be caused by limitations of the volume method of the echo scanner. The maximum sphere that fits entirely within the cone used for volume measurement has a volume of about 50 cc. Therefore, parts of the larger prostates will be outside this region of interest, resulting in a smaller volume (table 3). The volume results of patients with a reference volume smaller than 50 cc are presented in table 2. The results of all methods improve, as noted by the average error. Although the scanner should be able to contain the entire prostate in its memory, the prostate volume is still underestimated in the 23 patients with a reference volume smaller than 50 cc. The automated results presented in tables 1 to 4 are comparable to the results that Terris and Stamey found with step-section volumetry,[9] although the average errors are smaller in our case.

Besides determination of the efficacy of drug therapies, prostate volume is used to assess PSA density. The PSA value is often used as an initial screening parameter in the diagnosis of prostate cancer. PSA is produced by epithelial

TABLE 2. *Subpopulation of 23 patients with prostate reference volume of 50 cc or less, the maximum volume of a sphere that fits within the cone used for volume measurements on the Kretz combison echo scanner*

	Reference Vol.	Clinical Vol.	Transverse Vol.	Automated Vol.
Mean cc vol. (range)	37.2 (21–49)	28.2 (18–41)	23.5 (15–34)	37.2 (26–53)
Av. error ± SD (cc)	—	9.0 ± 5.3	13.7 ± 5.6	3.5 ± 2.8
Ratio coefficient ± SD	—	0.77 ± 0.13	0.63 ± 0.12	1.00 ± 0.13
Pearson's correlation coefficient	—	0.79	0.74	0.86

TABLE 3. *Subpopulation of 32 patients with prostate reference volume of more than 50 cc, the maximum volume of a sphere that fits within the cone used for volume measurements on the Kretz combison echo scanner*

	Reference Vol.	Clinical Vol.	Transverse Vol.	Automated Vol.
Mean cc vol. (range)	76.2 (51–172)	56.0 (35–124)	45.2 (27–127)	71.5 (40–124)
Av. error ± SD (cc)	—	20.0 ± 13.5	31.0 ± 14.9	9.7 ± 11.0
Ratio coefficient ± SD	—	0.73 ± 0.11	0.6 ± 0.1	0.91 ± 0.15
Pearson's correlation coefficient	—	0.91	0.88	0.89

TABLE 4. *Subpopulation of 49 patients with prostate reference volume of 100 cc or less*

	Reference Vol.	Clinical Vol.	Transverse Vol.	Automated Vol.
Mean cc vol. (range)	52.6 (21–97)	39.7 (18–71)	32.2 (15–62)	52.2 (26–88)
Av. error ± SD (cc)	—	12.9 ± 7.6	20.4 ± 9.4	5.0 ± 4.1
Ratio coefficient ± SD	—	0.76 ± 0.12	0.61 ± 0.11	1.00 ± 0.13
Pearson's correlation coefficient	—	0.91	0.89	0.94

cells of the prostate and the serum PSA value is a reflection of the amount of epithelial cell mass within the gland.[2] Stamey and Kabalin showed that elevation of PSA values (using the Yang assay) per cc tissue in prostate cancer tissue (3.5 ng./ml.) is approximately 11 times greater than in BPH tissue (0.31 ng./ml.).[4] Therefore, correction of PSA values for the prostate volume may enhance its discrimination possibility as a tumor marker.[2] At other clinics using the Hybritech assay, several values have been proposed as PSA density ratio for benign prostates.[3,19,20] These differences in benign PSA density ratios may be caused by the variability in volume measurements. For example, the average difference (−26%) in the clinical volume compared to the reference volume increases the PSA density ratio by 35.1%. Therefore, standardization of prostate volume determination is important to compare the benign PSA density ratios at different clinics.

Our study shows that large variations occur in clinical prostatic volume determination, which may have an effect on PSA density measurements as a helpful tool in discrimination of benign and malignant tissue. The automated determination can overcome the human variability in prostate volume. However, it is generally believed that the transition zone is the important element in the determination of PSA density. The automated volume method has no capability to determine the volume of the transition zone and, therefore, the rate of improvement of PSA density as a tumor marker by an improved total prostate volume determination is unknown.

CONCLUSIONS

The automated technique to calculate the volume of the prostate provides good results compared to the reference volume. The results are no longer dependent on the experience or interpretation of the urologist who performs the determination. It is only dependent on gray level transitions in the ultrasonographic images. Only in case of poor image quality is manual correction necessary to obtain correct volumes. For 1 of the 56 patients the automated method was unable to assess the volume because of the image quality and manual correction had to be performed.

For accurate and objective volume assessment, the automated method for prostate volume determination is a useful tool for the urologist. It can overcome the interpretative differences or "time pressure" errors in the manual outlining of the prostate contour during clinical examinations. The automated method can be used to standardize the prostate volume assessment and, therefore, it can improve the value of the prostate volume as a diagnostic parameter.

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